Fluctuations and the Ridge from RHIC to LHC

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RHIC & AGS Users Meeting, June 20, 2011

EMMI

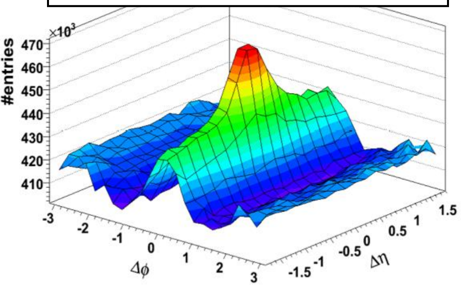
FIAS Frankfurt Institute for Advanced Studies

GOETHE UNIVERSITÄT FRANKFURT AM MAIN

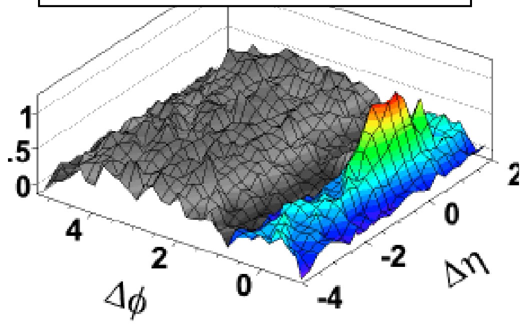
The Ridge

Hard Ridge

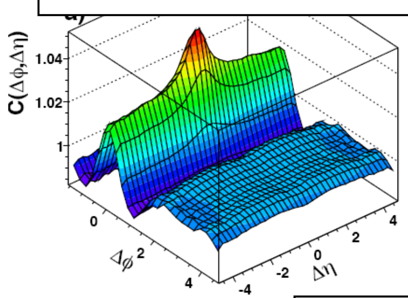
STAR



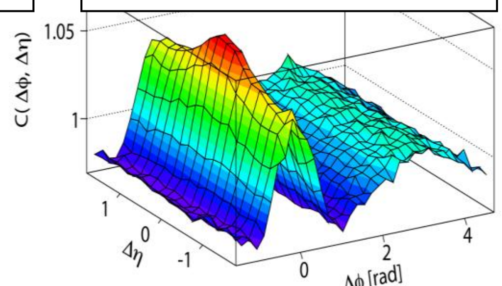
PHOBOS



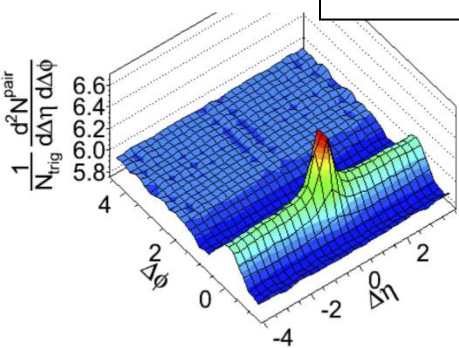
ATLAS

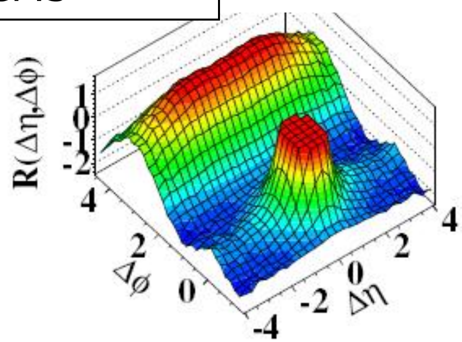


ALICE



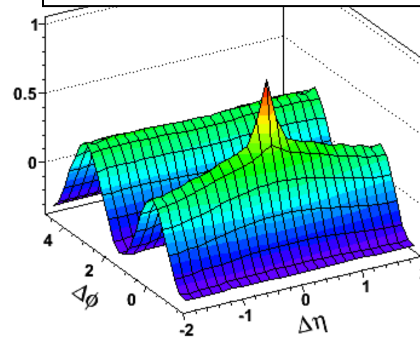
CMS





Soft Ridge

STAR



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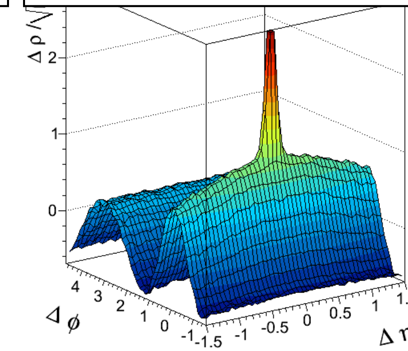


- **Hard Ridge:** high p_T trigger and lower p_T associates.

- **Soft Ridge:** correlations with no p_T restriction
  Soft Contribution to the Hard Ridge
  G.M., S.G. Nuclear Physics A 836 (2010) 43–58 arXiv:0910.3590

- **Flow based explanations:** correlations from source fluctuations, and transverse expansion must come from the same origin.

- **Long Range correlations:** correlations must emerge at early times.

- **Study the initial conditions!**

The Relation of v_n and Correlation Origins

$$\Delta\rho(\vec{p}_1, \vec{p}_2) = \iint_{positions} c(\vec{x}_1, \vec{x}_2) f(\vec{x}_1, \vec{p}_1) f(\vec{x}_2, \vec{p}_2)$$

Correlation function

$$c(\vec{x}_1, \vec{x}_2) \propto \mathcal{R}\, \delta(\vec{x}_1 - \vec{x}_2)\ \ \rho_{FT}(\vec{x}_1, \vec{x}_2)$$

Glasma flux tube correlations

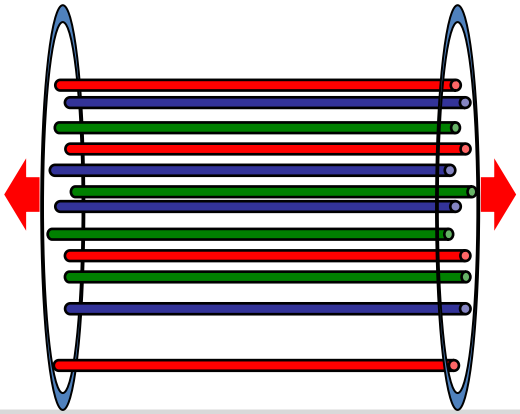
The correlation function makes $\Delta\rho$ a convolution

$$\Delta\rho \propto 1 + 2\sum_{n=1}^{\infty} \langle v_n(p_{T1}) v_n(p_{T2}) \rangle \cos(n\Delta\phi)$$

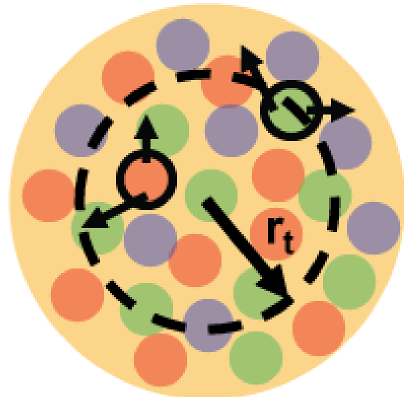
<…> = average over flux tube distribution

Fourier coefficients reveal spatial correlations

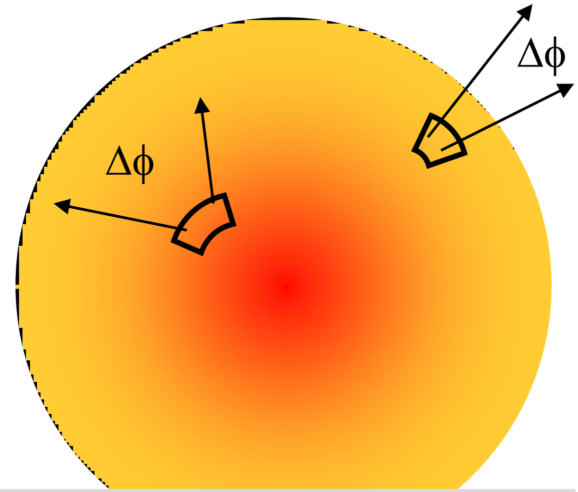
Fluctuating Initial Conditions + Flow



~0.1 fm/c



~1 fm/c



Freeze out

CGC-Glasma flux tube correlation function:

•Correlated partons come from the same tube

•Tube size ~Q^{-2}_s the saturation scale

•The correlation strength $\mathcal{R}$ depends on tube fluctuations

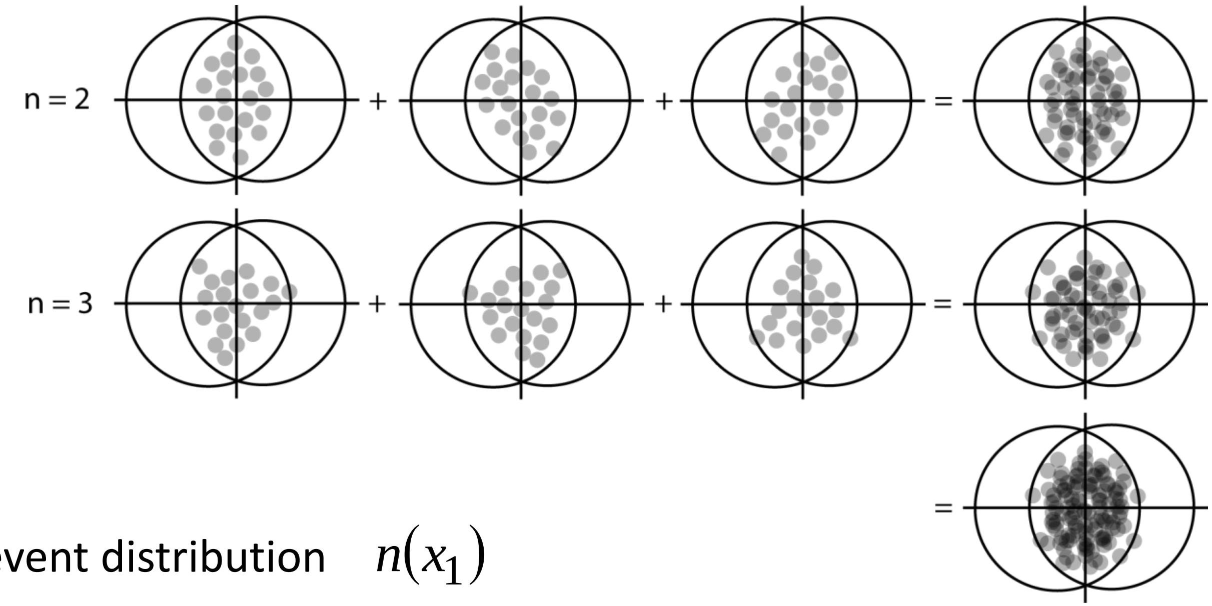
Flow boosts fluid cells based on their initial radial position

• Flow enhances the azimuthal distribution; cells starting at a large radius are pushed into a narrower $\Delta\phi$ opening angle.

• Initial correlations in space result in final correlations in momentum.

S. Voloshin ; Pruneau, Gavin & Voloshin; Dumitrum , Gelis, McLerran & Venugopalan; Gavin. McLerran & G.M.

The Correlation Function



Event average

Event by event distribution $n(x_1)$

Event average distribution $\langle n(x_1) \rangle$

$$c(x_1, x_2) = \left\langle \left[n(x_1) - \langle n \rangle \right] \left[n(x_2) - \langle n \rangle \right] \right\rangle$$

$$c(\vec{x}_1, \vec{x}_2) = \mathcal{R}\ \delta(r_t) \rho_{FT}(R_t)$$

Transverse Coordinates

$\vec{r}_t = \vec{r}_1 - \vec{r}_2 \quad \vec{R}_t = (\vec{r}_1 + \vec{r}_2)/2$

Glasma Dependence

Gluon Rapidity Density   Kharzeev & Nardi

$$\frac{dN}{dy} = \frac{gluons}{tube} \times \langle N_{FT} \rangle \propto \langle N_{FT} \rangle \alpha_s^{-1}(Q_s^2)$$

Correlations of N_{FT} Flux Tubes :
fluctuations in tube number

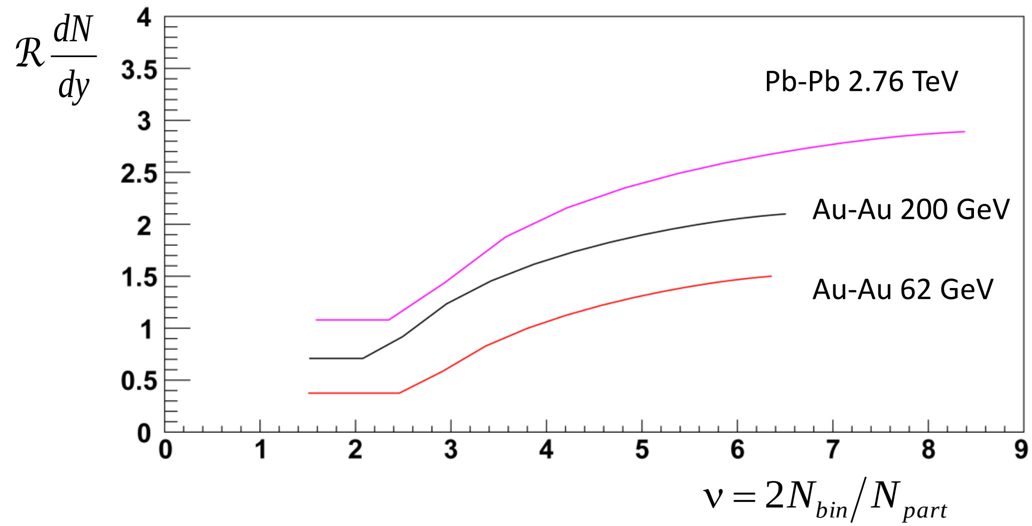
$$\mathcal{R} = \frac{Var(N) - \langle N \rangle}{\langle N \rangle^2} \propto \frac{1}{\langle N_{FT} \rangle}$$

Glasma Correlation Scale

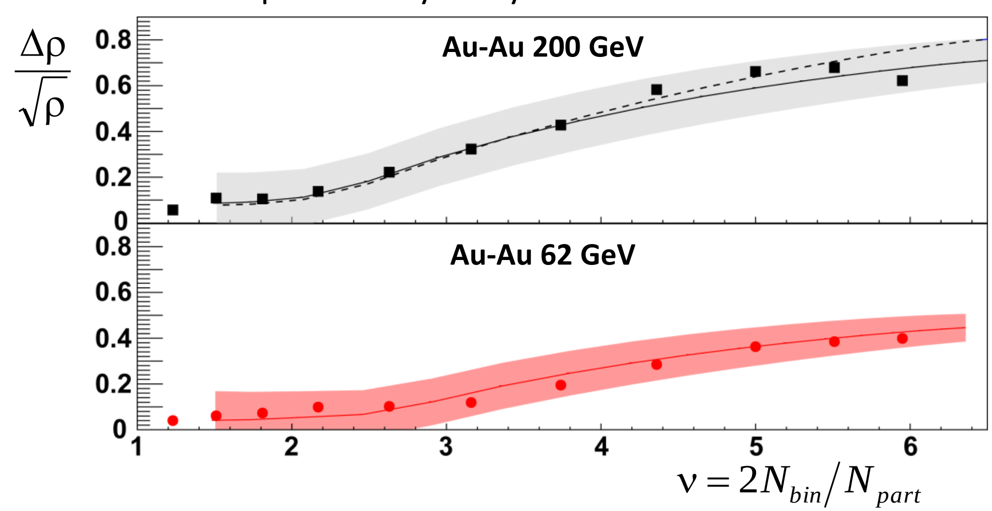
$$\mathcal{R}\frac{dN}{dy} \propto \alpha_s^{-1}(Q_s^2)$$

Glasma Fluctuations scale long range correlations, depending only on the Q_s.

Dumitru, Gelis, McLerran & Venugopalan;
Gavin, McLerran & GM



STAR preliminary analysis of both 200 and 62 GeV



Blast Wave Expansion

Boltzmann Distribution

$$f(\vec{x},\vec{p}) = e^{-u^{\mu}p_{\mu}/T}$$

Hubble-like Expansion

$$\gamma_T \vec{v}_T = \lambda \vec{r}$$ Radial Expansion only

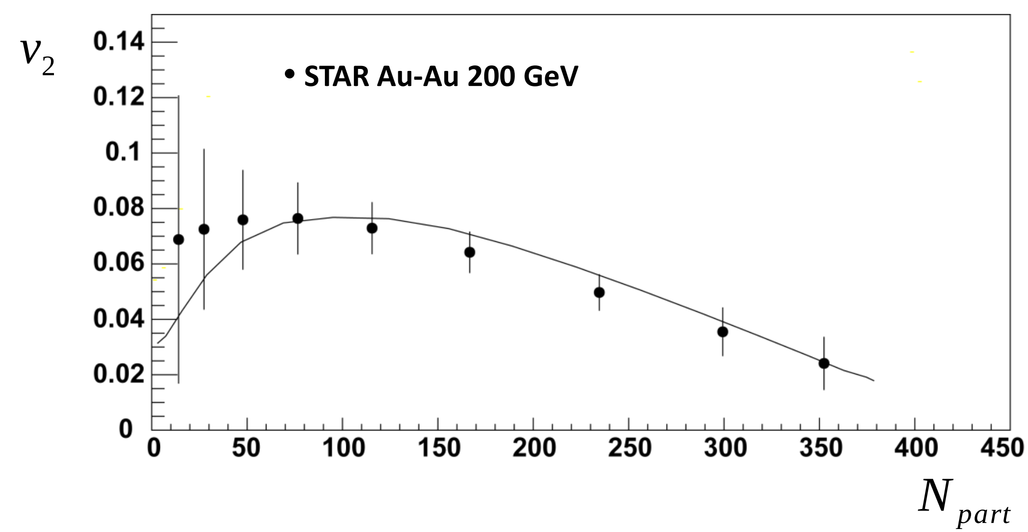
$$\gamma_T \vec{v}_T = \varepsilon_x x\hat{x} + \varepsilon_y y\hat{y}$$ Anisotropic Expansion

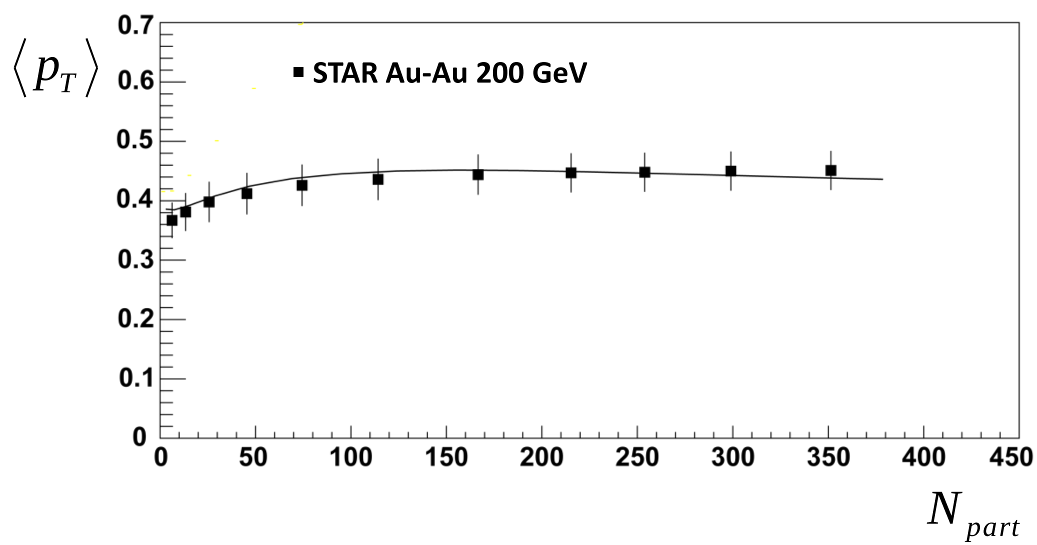
Momentum Distribution

$$\rho_1(\vec{p}) \equiv \frac{dN}{dy d^2 p_T} = \int f(\vec{x},\vec{p}) d\Gamma$$

Cooper-Frye Freeze Out

$$d\Gamma = p^{\mu} d\sigma_{\mu} = \tau_F m_T \cosh(y-\eta) d\eta d^2\vec{r}$$





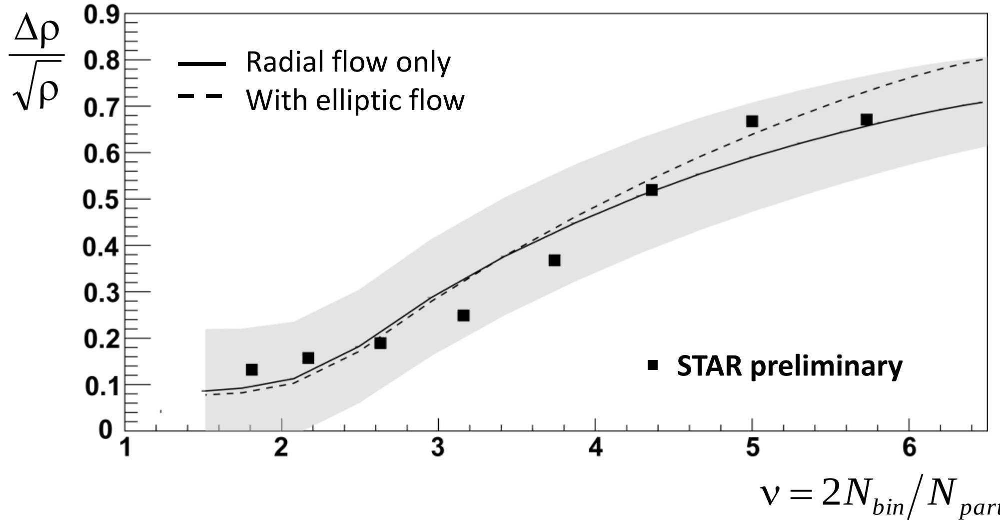
Schnedermann, Sollfrank & Heinz; Retiere & Lisa

The Near Side Ridge Amplitude

$$\Delta\rho(\vec{p}_1,\vec{p}_2) = \text{pairs} - (\text{singles})^2$$

$$\Delta\rho(\vec{p}_1,\vec{p}_2) = \iint\limits_{positions} c(\vec{x}_1,\vec{x}_2)\, f(\vec{x}_1,\vec{p}_1)\, f(\vec{x}_2,\vec{p}_2)$$

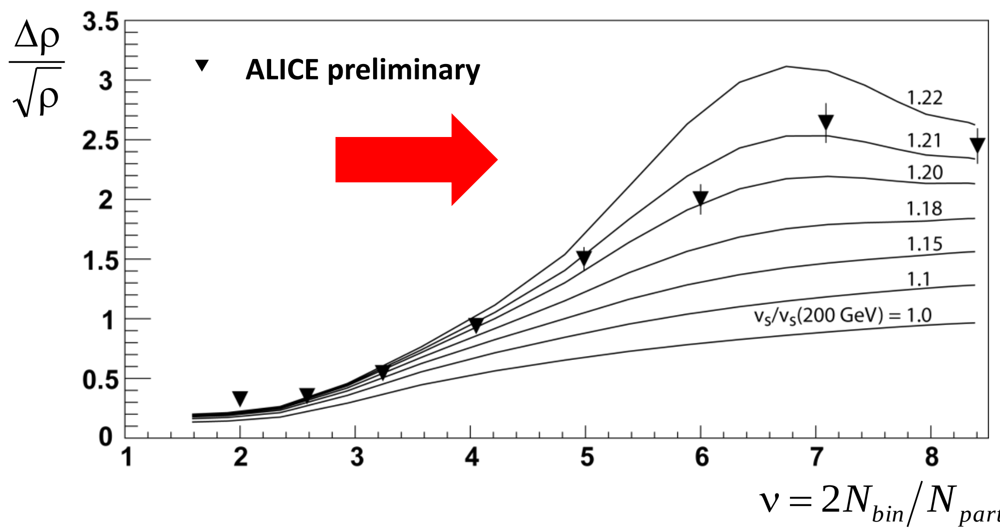
$$\frac{\Delta\rho}{\sqrt{\rho}} = \mathcal{R}\,\frac{dN}{dy}\,\frac{\iint\limits_{momenta} \Delta\rho(\vec{p}_1,\vec{p}_2)}{\iint\limits_{momenta} \rho_1(\vec{p}_1)\rho_1(\vec{p}_2)}$$



- Elliptic flow enhances correlations in peripheral collisions.

Sorensen et al.

- Glasma correlation scale drops with centrality
- Error band from uncertainty in blast wave parameters and calculation of Q_s.
- A increased flow velocity is needed to explain the data.



FIND: ridge amplitude sensitive to blast wave velocity

Momentum Conservation

Correlation function

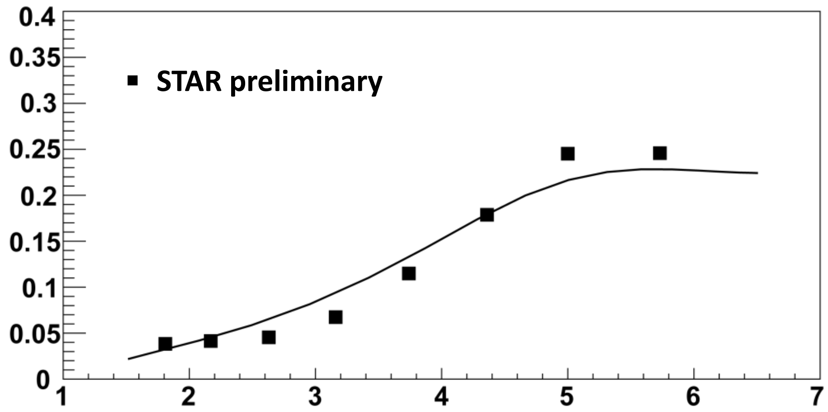
$$c_{mom}(\vec{p}_1, \vec{p}_2) = -\frac{2}{N_{tot}^{eff}\left\langle p_T^2 \right\rangle}\left(\frac{p_{1,x}p_{2,x}}{1+v_2''} + \frac{p_{1,y}p_{2,y}}{1-v_2''}\right)$$

$$v'' = \left\langle p_T^2 \cos(2\Delta\phi)\right\rangle / \left\langle p_T^2 \right\rangle$$

Borghini, PoS LHC07:013,(2007)

$$\frac{\Delta\rho_{mom}}{\sqrt{\rho}} = -\mathcal{A}_{mom}\cos(\Delta\phi)$$

cos(Δϕ) amplitude



$\nu = 2N_{bin}/N_{part}$

- Global momentum conservation: N_{tot} includes undetected particles
- Effective correlation length: e.g. in peripheral collisions, all particles share momentum, and in central collisions, momentum is shared locally in rapidity by a smaller fraction of the total produced particles.

Chajecki, Lisa

Fit Functions

“We shouldn’t speak about the near side and
the away side of the ridge as separate things.” ~QM, Annecy

$$\frac{\Delta\rho}{\sqrt{\rho}}$$ **= Flux Tubes + Momentum Conservation + Elliptic Flow**

$$\frac{\Delta\rho}{\sqrt{\rho}}$$ **= Offset + Gaussian + A *cos*(Δφ) + B *cos*(2Δφ)**

Fit to Calculation

- Calculated offset must be zero or positive
- Given a fixed Gaussian width, only the offset is allowed to change
- Alternatively put constraints on the offset and fit the width.
- $\chi^2 < 1$
- $\mathrm{Cos}(2\Delta\phi)$ amplitude from Blast Wave v_2 calculation fit to data
- Fourier fits may be easier to quantify.

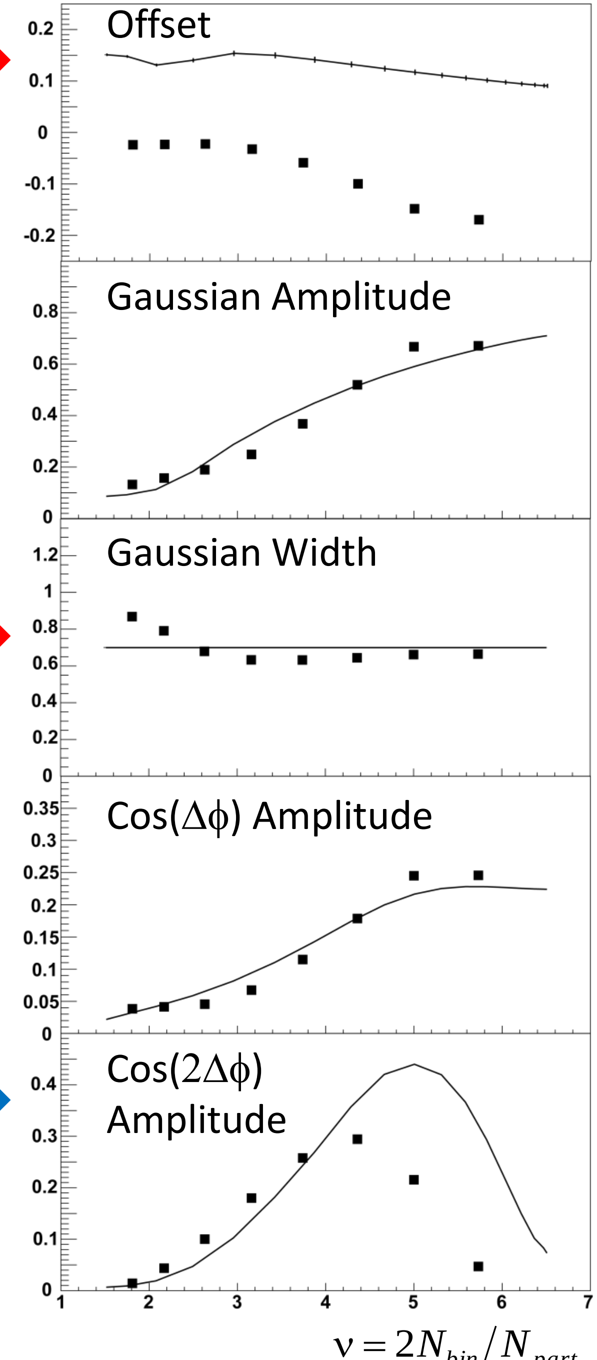
Fit Fixed to Calculation

Width Fixed to 0.7

Fit Fixed to Calculation

Fit Fixed to Calculation

All Data points: STAR preliminary.



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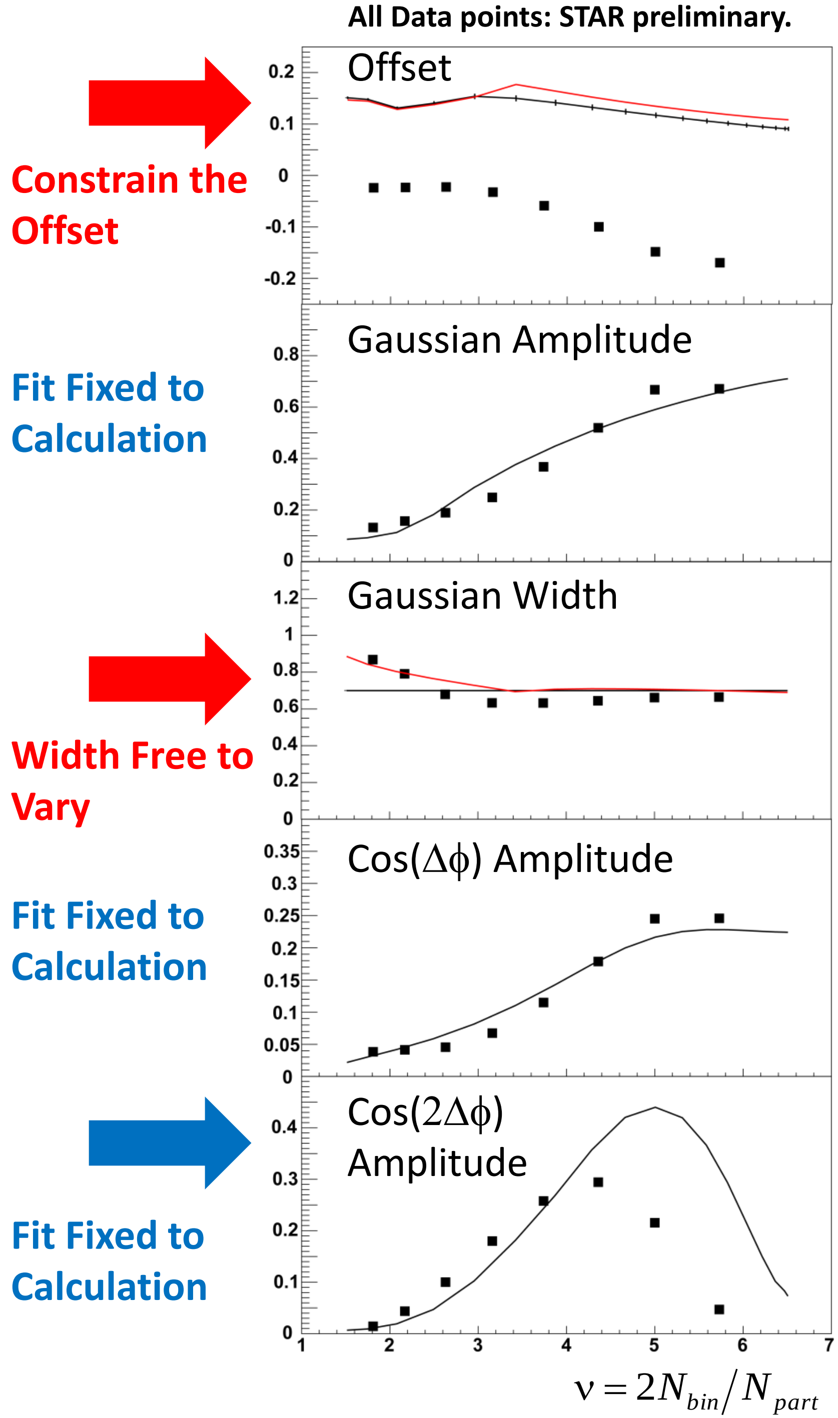


Fit Functions II

$\frac{\Delta\rho}{\sqrt{\rho}}$ **= Flux Tubes + Momentum Conservation + Elliptic Flow**

$$\frac{\Delta\rho}{\sqrt{\rho}} = \frac{a_0}{2} + a_1 \cos(\Delta\phi) + a_2 \cos(2\Delta\phi) + a_3 \cos(3\Delta\phi)$$

$$v_n \propto \sqrt{\frac{a_n}{2\langle N \rangle}}$$ n>0

Fourier Fits to Calculation: Au-Au 200 GeV

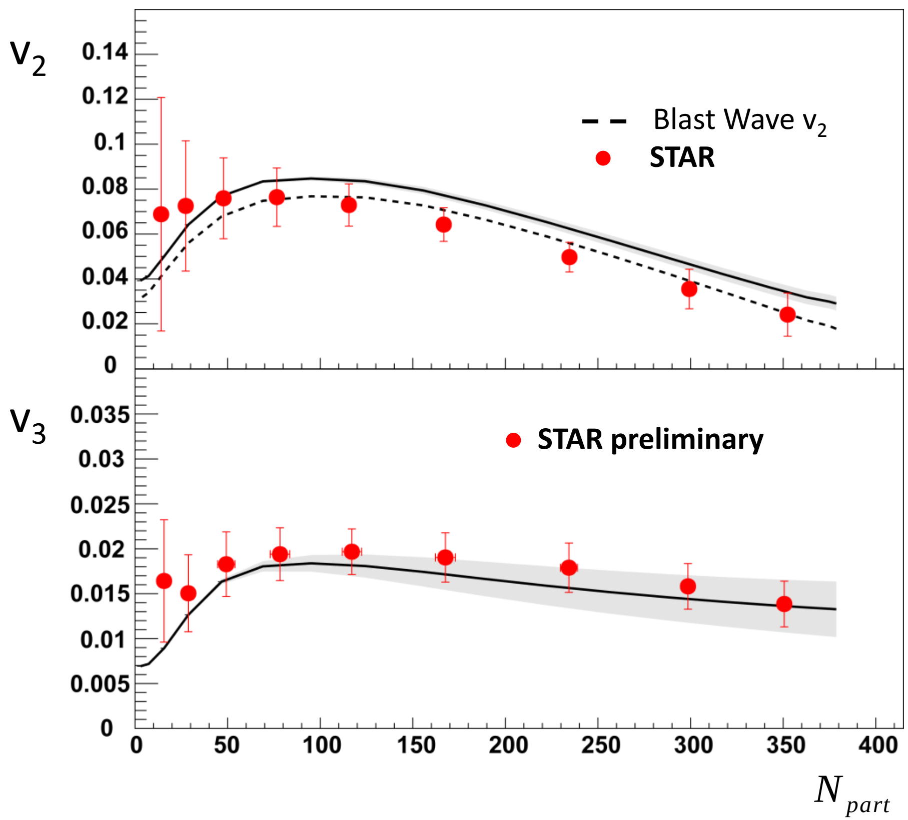
$$\langle v_n^2 \rangle \propto \int \rho_{FT} \left[\iint f(\vec{x}, \vec{p}) \cos(n\Delta\phi) \right]^2$$

v_2

- Geometry + Fluctuations.
- Error band from fitting
- Dashed line: Blast wave v_2

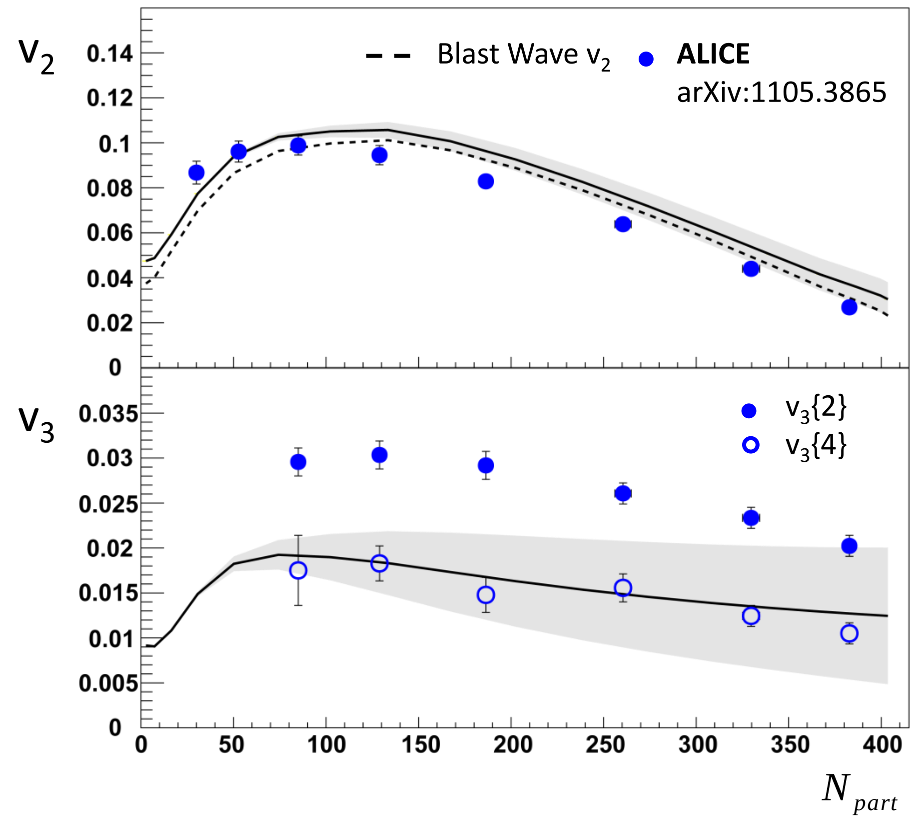
v_3

- Only from fluctuating sources.
- Simultaneous agreement with ridge amplitude



Fourier Fits to Calculation: Pb-Pb 2.76 TeV

- **Blast Wave parameters**: adjusted to fit v_2 and $<p_T>$ $v_s = 1.05v_s(200\text{ GeV})$ $T_F = 1.1T_F(200\text{ GeV})$
- Recall we needed $v_s = 1.21v_s(200\text{ GeV})$ to explain the ridge amplitude.
- $\mathbf{v_3}$: Only from fluctuating sources. Fits $v_3\{4\}$ but not $v_3\{2\}$. Missing components need to be investigated.
- Non-Flow correlations such as jets and resonance decays also need investigating.



Conclusion

CGC-Glasma Correlation Scale: $\mathcal{R}\, dN/dy$

- Long range rapidity correlations must be induced at early times.
- Gluon density per source (flux tube)
- Number of sources and distribution of sources
- Energy and centrality dependence

Glasma + Flow

- Final state correlations in momentum space based on initial correlations in position space come from a convolution of density distributions.
- The ridge amplitude is sensitive to anisotropic flow velocity.

"Does v_3 leave any room for a ridge?"

- Fluctuating sources + flow produce a ridge… and v_3.
- Spatial correlations convolute momentum distributions.
- Agreement with ridge measurements at STAR yields comparable v_3.

From RHIC to LHC:

- Ridge amplitude argues for large flow velocity in Pb-Pb 2.76 TeV.
- Simultaneous fitting of v_2 and $\langle p_T \rangle$ argue strongly for smaller flow velocity.
- v_3 from fluctuations underestimates measured $v_3\{2\}$ at ALICE, but agree with $v_3\{4\}$.

Fourier Fits to Calculation: Au-Au 200 GeV

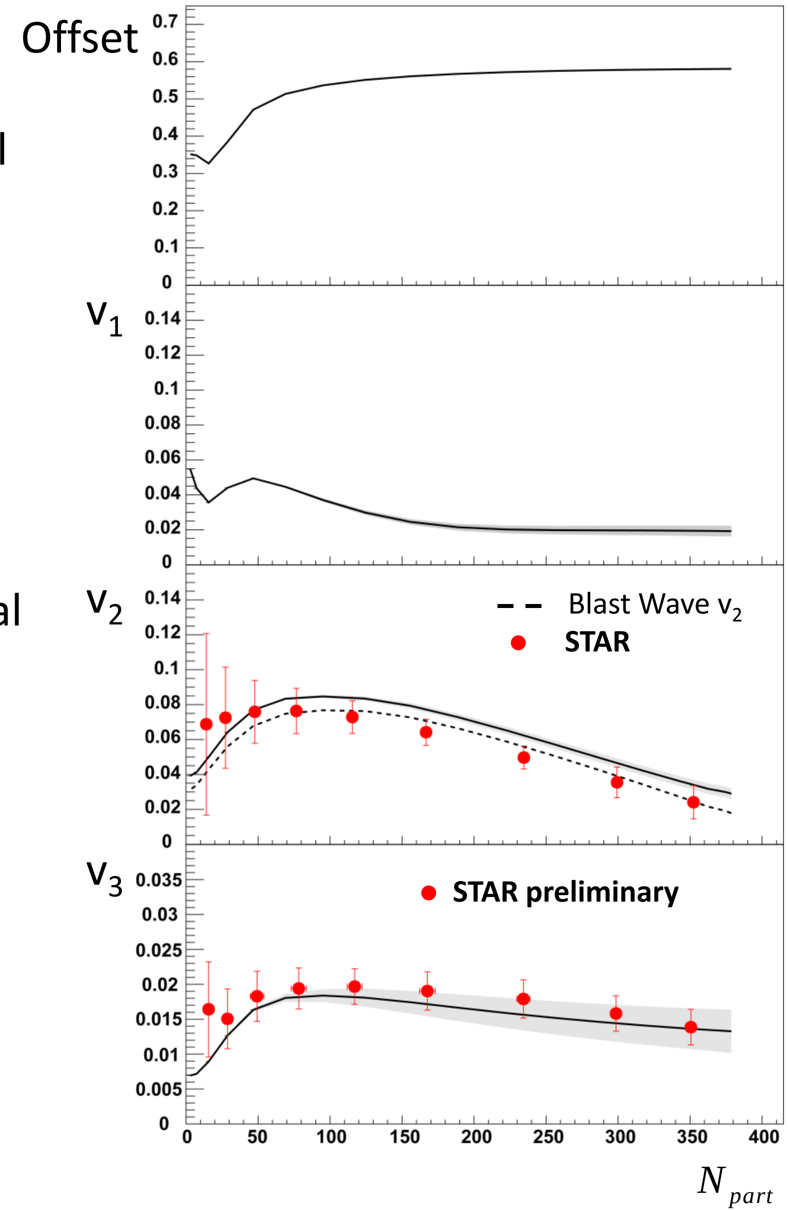
- **Offset**: relatively flat with centrality until peripheral collisions. Could be a good measure of energy dependence.

$$\mathcal{R} = \frac{Var(N) - \langle N \rangle}{\langle N \rangle^2}$$ Correlation Strength

- $\mathbf{v_1}$: Fluctuations – Momentum conservation. Central collisions are at a similar scale to v_3.

- $\mathbf{v_2}$: Geometry + Fluctuations.

- $\mathbf{v_3}$: Only from fluctuating sources.



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